As originally published in the SMTA International Conference Proceedings.

BOARD LEVEL RELIABILITY COMPARISON OF LEAD FREE ALLOYS

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ABSTRACT

Board level reliability testing was used to compare six lead free alloys to tin-lead eutectic using a 98 ball Wafer Level Chip Scale Package (WLCSP). The component had a 0.5mm Ball Grid Array (BGA) pitch, and Al/NiV/Cu pad metallization. Thermal cycling (4 conditions), cyclic bend (2 conditions), cyclic drop (3 conditions), and solder joint array tensile testing (3 conditions) were utilized to compare the alloys. The effects of reflow conditions and aging conditions were quantified.

In drop testing, first failures were in the range of 4 to 1000 drops. Most samples failed by a mixture of bulk solder and interface failure. Drop test life improved with increased Ag content. The effect of mild aging after surface mount was positive for most alloys. The effect of multiple reflows was mixed.

In solder joint array tensile testing, the Ductile-to-brittle transition strain rate (DTBTSR) was in the range of 0.3/sec to 80/sec. DTBTSR improved with decreasing Ag content and with room temperature aging, but it degraded with multiple reflows.

In cyclic bend testing, first failures were in the range of 1000 to 5000 cycles. SAC405 and 63Sn37Pb had the best performance. A 3mm bend deflection had 2x to 3x longer life compared to a 4mm bend deflection.

In temperature cycling, first failures were in the range of 100 to 6000 cycles. Fatigue life increased with Ag content for the SAC alloys. Sn0.7Cu showed good performance under all conditions. 63Sn37Pb showed good performance under 35C<=>110C condition. Sn3.5Ag had poor performance under all conditions due to voiding and some interface failures.

Key words: Board Level Reliability, Lead Free Solder, Thermal Cycle Test, Cyclic Bend Test, Cyclic Drop Test

INTRODUCTION

Lead free solders have been shipping in production for several years. However, there is no clear convergence on the alloy of choice for the electronics industry. Instead, there seems to be continuous work on new alloy derivatives in an effort to improve performance. A tin rich system is by far the most commonly used. Typical additions are silver and copper. After that, minor additions of nickel, bismuth, antimony, etc, have been employed.

Ball alloy selection for a given BGA package depends on factors such as pad metallization, reflow process conditions, test handling environment, and field application environment. Solder joint failures can occur due to several possible causes

- impact loading during test socketing
- impact loading during shipping
- PCB bending during product assembly
- PCB bending during key pad actuation
- PCB bending during drop impact
- thermal expansion mismatch during temperature cycling
- thermal expansion mismatch during power cycling
- creep rupture due to PCB bending in product assembly

No single lead free alloy has proven to be superior for all combinations of pad metallization, process conditions, and field use environment. Hence, the industry uses several alloys today, and will continue to do so in the future.

The purpose of the present study is to evaluate the board level reliability of several lead free alloys under a range of accelerated test conditions using a common test vehicle. A 98 ball Wafer Level Chip Scale Package (WLCSP) was utilized for the study and it was tested under thermal cycling (4 conditions), cyclic bend (2 conditions), cyclic drop (3 conditions), and solder joint array tensile testing (3 conditions). The effects of surface mount reflow conditions and aging after surface mount were quantified. The alloys evaluated in this work are listed in Table 1. All of these alloys are used in production today. Tin-lead eutectic was also evaluated as the control sample.

Table 1.
Solder Alloys

Alloy	Name	Code
63Sn37Pb	Eutectic SnPb	6337
Sn4.0Ag0.5Cu	SAC405	4005
Sn3.0Ag0.5Cu	SAC305	3005
Sn1.2Ag0.5Cu0.05Ni	SAC125Ni	1255
Sn1.0Ag0.5Cu	SAC105	1005
Sn3.5Ag	Eutectic SnAg	6535
Sn0.7Cu	Eutectic SnCu	9307

TEST VEHICLE AND SAMPLE PREPARATION

The test vehicle used in the present study was a 98 ball WLCSP with a 0.5mm Ball Grid Array (BGA) pitch, and Al/NiV/Cu pad metallization. The component dimensions are shown in Figure (1a), and a schematic of the cross sectional dimensions after mounting to the test board is shown in Figure (1b).

The test boards had 4 metal layers and a polyimide based laminate material set. The composite elastic modulus measured by Dynamic Mechanical Analysis (DMA) in 3-point bending mode was 16.3 GPa at -55C and 13.5 GPa at 125C. The composite thermal expansivity was 18.1ppm/C in the X-direction and 14.2ppm/C in the Y-direction over the temperature range from -55C to 125C.

The surface mount reflow profile is shown in Figure 2. Either 1 pass or 4 pass reflow conditions were utilized. After SMT, the samples were aged at either 22C or 125C before testing. Samples were surface mounted by using a flux only process (not solder paste) in order to minimize voiding effects and to measure the baseline performance of each alloy without the influence of mixing it with a solder paste alloy. However, it is recognized that in most applications, the BGA alloy does mix with the SMT solder paste alloy to form the final solder joint alloy. For example, the BGA alloy might be SAC105 and the solder paste alloy might be SAC305, so the final alloy might be approximately SAC125. This effect was not studied in the present work.

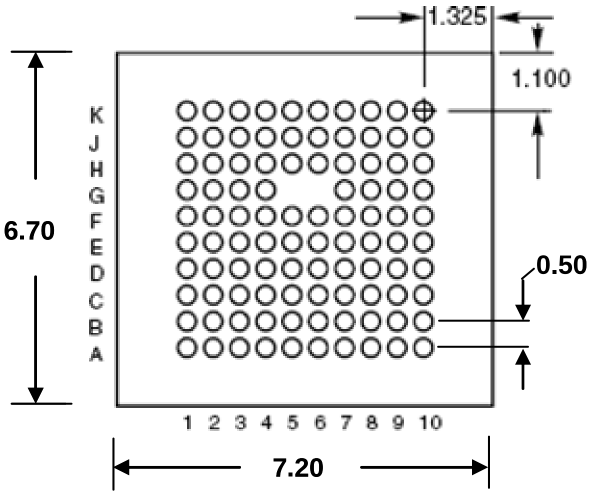
CYCLIC DROP TEST

Drop testing was conducted per JEDEC Standard JESD22-B111. The input shock pulse was 1500G's, half sine, with 0.5msec duration. The event detector was set to trigger at 1000 Ohms. A representative test board with samples mounted on it is shown in Figure 3. Exceptions to the JEDEC standard were that the test board was 4 metal layers (instead of 1-4-1 construction) and 5 units were mounted per board (instead of 15 or 4). All 5 samples were included in the data analysis. Three conditions were tested for each alloy type

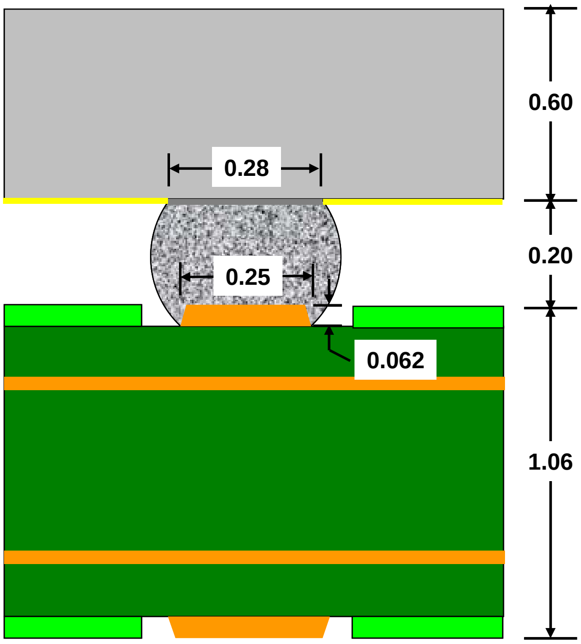
- 1 pass reflow + 24hrs / 22C aging
- 4 pass reflow + 24hrs / 22C aging
- 1 pass reflow + 6months / 22C aging

A Weibull plot for the case of 1 pass reflow + 24hrs / 22C aging is shown for all alloy types in Figure 4. The performance is quite good, with nearly all samples passing over 200 drops before failure. The failure mode summary for this data set after 2650 drops is shown in Figure 5. Solder failure was the most prevalent failure mode. The higher Ag content alloys had more non-failed samples at the end of the test.

A Weibull plot for the case of 4 pass reflow + 24hrs / 22C aging is shown for all alloy types in Figure 6. The performance has degraded compared to Figure 4, especially for the 63Sn37Pb alloy. It should be noted that same reflow profile was used for alloy alloys. Hence, the 63Sn37Pb alloy spent much longer time above liquidus (183C) compared to the lead free alloys. A more realistic comparison for future work would be to optimize the profile for 63Sn37Pb (maybe 215C peak instead of 245C).



a) WLCSP dimensions.



b) Cross sectional dimensions

Figure 1. Sample configuration.

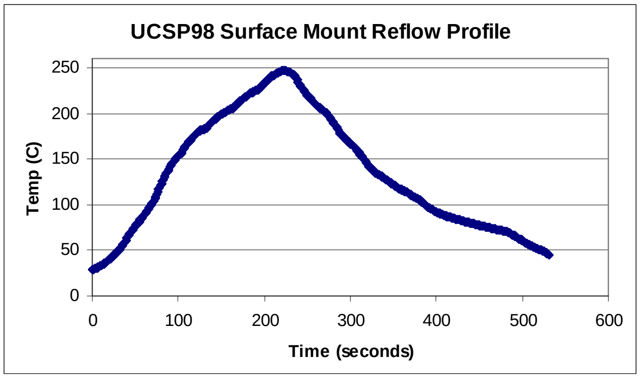


Figure 2. Surface mount reflow profile.

The failure mode summary for this data set is shown in Figure 7. Solder failure was the most prevalent failure mode. For the higher Ag content alloys, trace failures increased, and there were more non-failed samples at the end of the test.

A Weibull plot for the case of 1 pass reflow + 6months / 22C aging is shown for all alloy types in Figure 8. The performance is quite good, with nearly all samples passing over 200 drops before failure. The failure mode summary for this data set is shown in Figure 9. Solder failure was the most prevalent for low Ag content alloys, and trace failure was more common for high Ag content alloys. There were many more non-failed samples at the end of the test compared to the other two data sets

A summary of the most prevalent failure modes for all the "solder" failures is shown in Table 2. Pictures of representative fracture surfaces for solder failures are shown in Table 3. Nearly all solder joint failures resulted from crack propagation near the WLCSP interface. The crack path was either through the bulk solder or through the interface intermetallics. In many cases, there was a mixed fracture path. SAC105, SAC125Ni and Sn3.5Ag showed a higher incidence of bulk solder failure mode. SAC305, SAC405, Sn0.7Cu, and 63Sn37Pb showed more mixed failure mode. Only 63Sn37Pb alloy with 4X reflow showed clean interface failure mode, and the resulting poor performance was clearly shown in Figure 6. Some of the joints had small voids at the WLCSP pad interface. This was especially evident for Sn3.5Ag samples. The void size appeared to grow with 4X reflows.

A summary of the drop test results and alloy ranking when considering the <u>first failure</u> of the population are given in Table 4 and Figure 10. SAC405 was the best overall performer. Since the failure mode was mixed between interface and bulk solder failure, and the drop test life was relatively long (100s to 1000s of drops) it is likely that the higher creep resistance of SAC405 resulted in improved performance. Simulation results have shown that higher creep resistance results in a lower strain energy density per drop "cycle," and a longer predicted fatigue life [1]. This should be true as long as the applied strain rate has not exceeded the ductile-to-brittle transition strain rate.

The effect of 6 months room temperature aging was mixed. It extended drops to first failure for SAC105, SAC125Ni, 63Sn37Pb, and Sn3.5Ag.

The effect of multiple reflows was mixed. It improved performance for SAC105 and SAC125Ni, but degraded performance for 63Sn37Pb and Sn3.5Ag

A summary of the drop test results and alloy ranking when considering the <u>mean failure</u> of the population are given in Table 5 and Figure 11. These results are mostly consistent with the results comparison based on first failure. SAC405 was the best overall performing alloy.

The effect of 6 months room temperature aging was positive for almost every alloy. Theoretically, this would be expected if the effect of aging were to soften the solder to a point where the failure mode changed from interface failure to bulk solder failure. Such a change generally improves drop test life.

In the present study, the failure modes were either bulk solder or mixed in the un-aged condition. Furthermore, the failure mode did not change significantly with aging based on Table 2. Hence it is not obvious why the life improved with room temperature aging for most alloys.

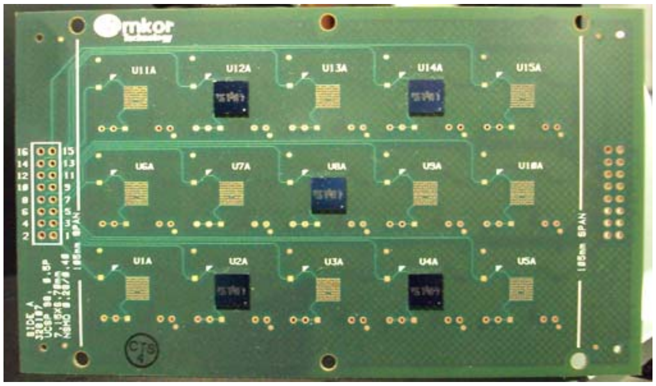


Figure 3. Drop test board with assembled units

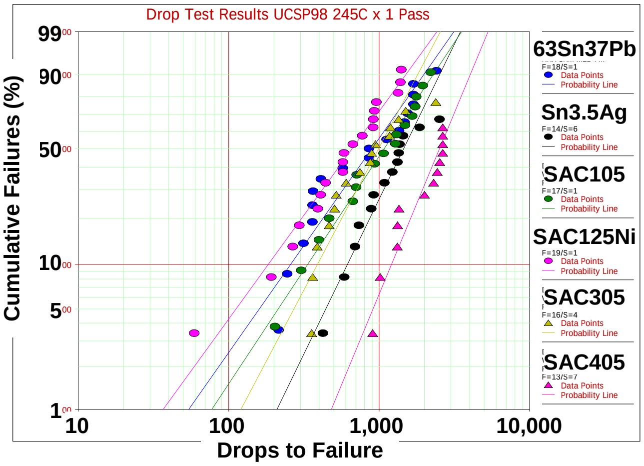


Figure 4. Drop test results for 1 pass reflow + 24hrs / 22C aging.

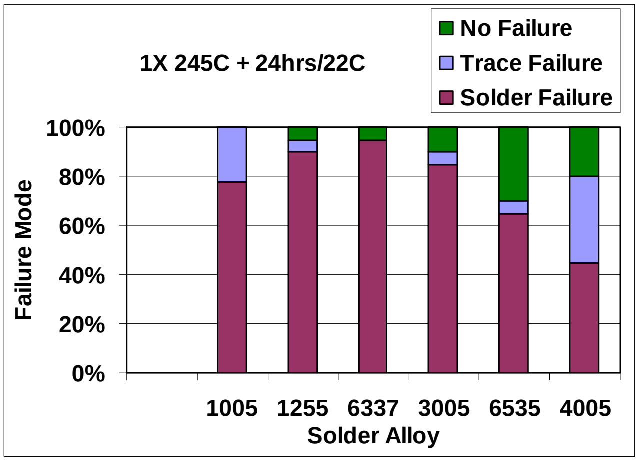


Figure 5. Drop test failure mode summary after 2650 drops for 1 pass reflow + 24hrs / 22C aging.

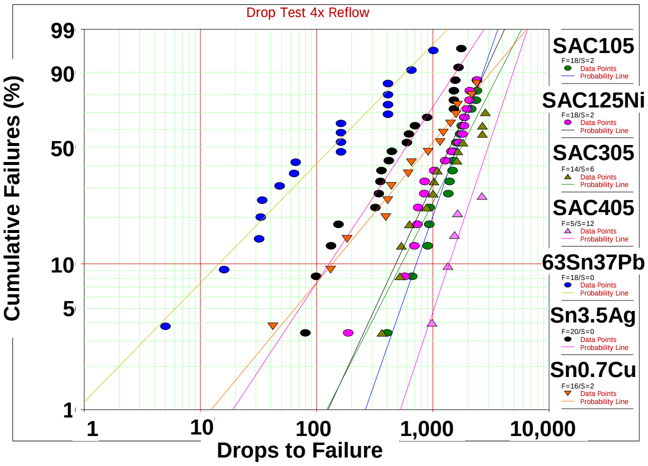


Figure 6. Drop test results for 4 pass reflow + 24hrs / 22C aging.

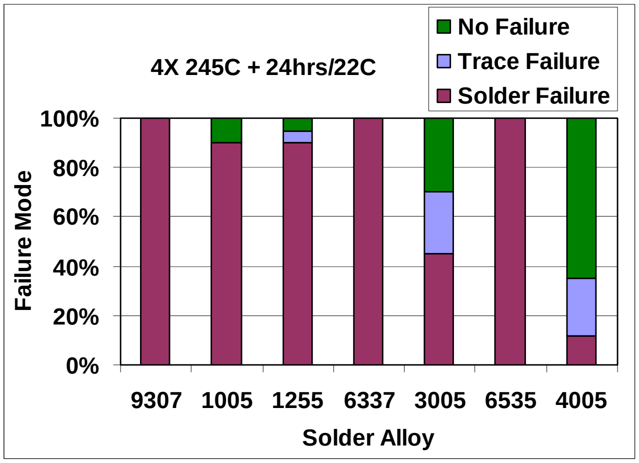


Figure 7. Drop test failure mode summary after 2650 drops for 4 pass reflow + 24hrs / 22C aging.

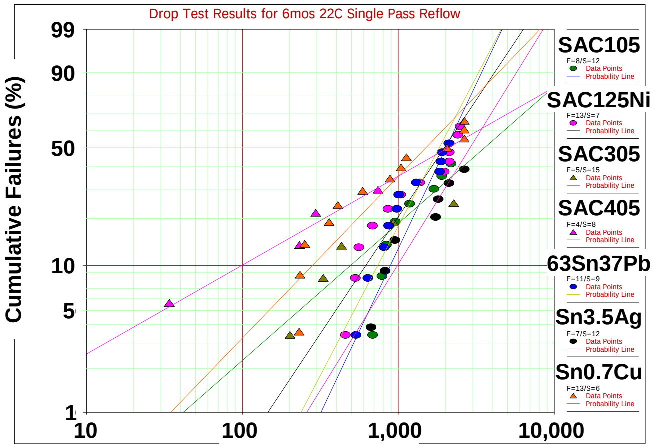


Figure 8. Drop test [illegible] reflow + 6 months / 22C aging.

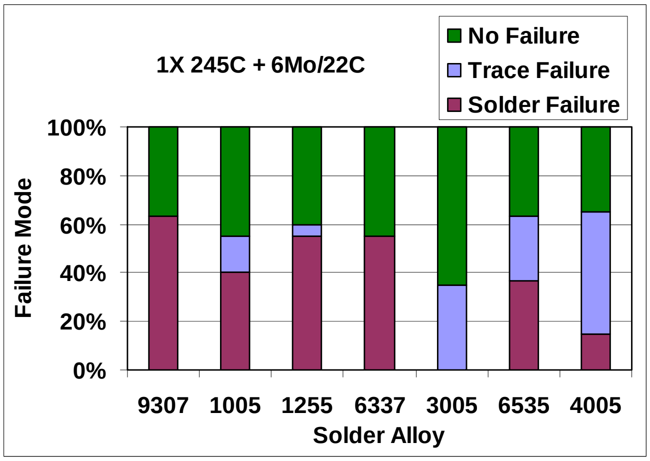


Figure 9. Drop test failure mode summary after 2650 drops for 1 pass reflow + 6 months / 22C aging.

Table 2.
Drop test failure mode summary for samples with failures occurring in the solder joint

	1 pass reflow + 24hrs / 22C	4 pass reflow + 24hrs / 22C	1 pass reflow + 6Mo / 22C
63Sn37Pb	Mixed	Interface	Bulk / Mixed
SAC405	Mixed	Interface / Mixed	Interface / Mixed
SAC305	Mixed	Mixed	Interface / Mixed
SAC125Ni	Bulk	Bulk	Bulk / Mixed
SAC105	Bulk / Mixed	Bulk / Mixed	Bulk / Mixed
Sn3.5Ag	Bulk	Bulk	Bulk
Sn0.7Cu		Interface / Mixed	Mixed

Table 3

Fracture surfaces for drop tests

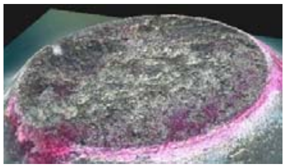
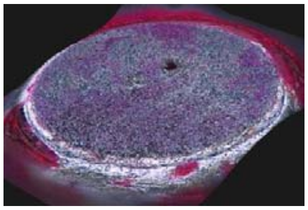
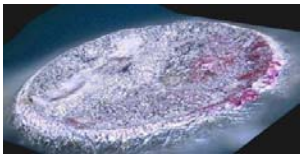
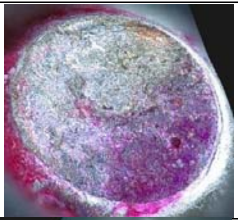
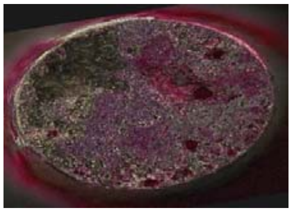
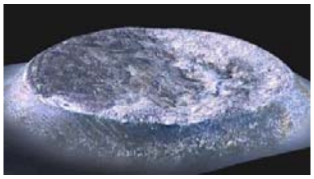
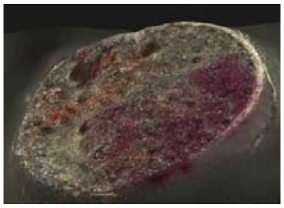
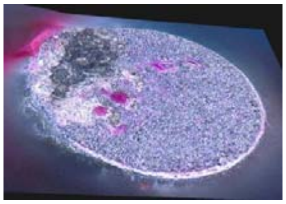
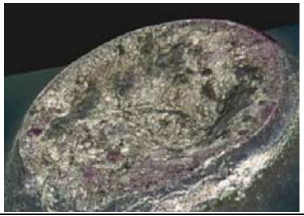
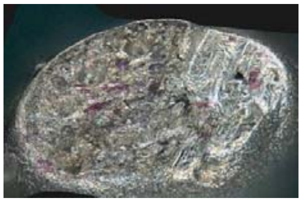
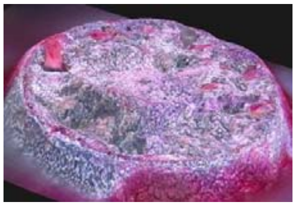
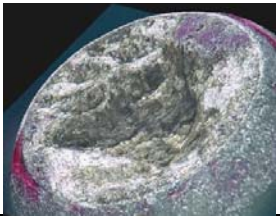
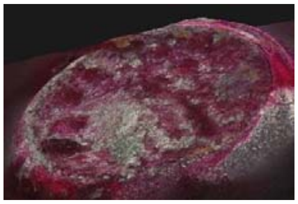
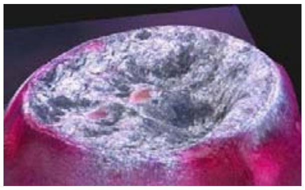
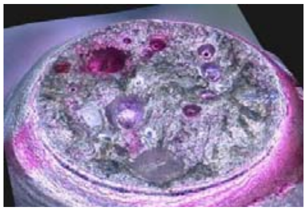
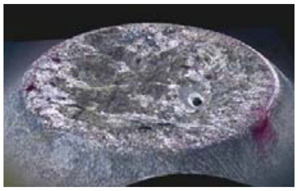
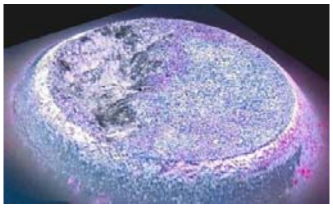
	1 Pass Reflow + 24hrs / 22C	4 Pass Reflow + 24hrs / 22C	1 Pass Reflow + 6Mo / 22C
63Sn37Pb			
Sn4.0Ag0.5Cu			
Sn3.0Ag0.5Cu			
Sn1.2Ag0.5Cu0.05Ni			
Sn1.0Ag0.5Cu			
Sn3.5Ag			
Sn0.7Cu			

Table 4
Alloy ranking for 1st Failure in drop tests

	9307	1005	1255	6337	3005	6535	4005
Ranking 1X245C + 6Mo/22C	5	1	4	3	6	2	7
Ranking 1X245C + 24hr/22C		5	6	4	3	2	1
Ranking 4X245C + 24hr/22C	6	2	4	7	3	5	1
Effect of 22C Aging		+	+	+	-	+	--
Effect of Multiple Reflows		+	+	--	=	-	=

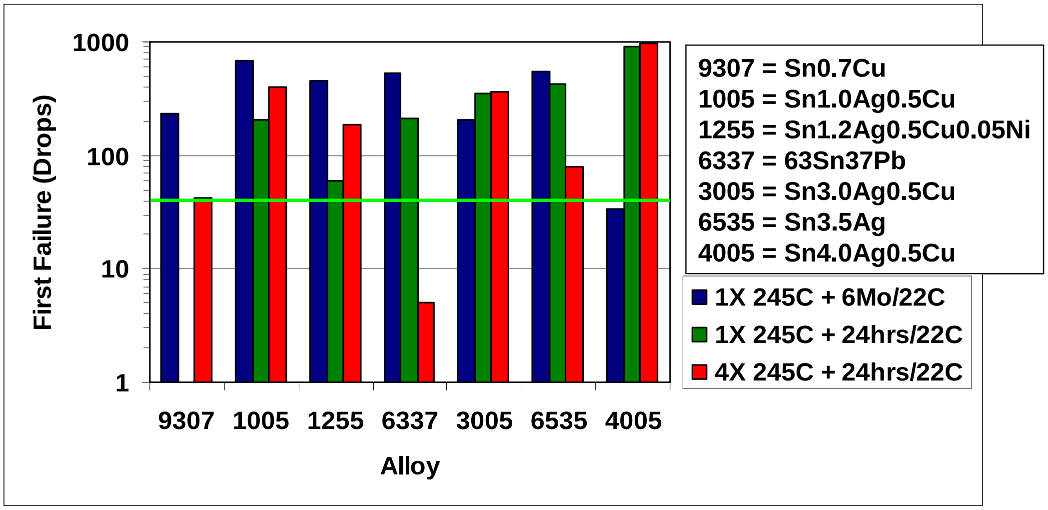


Figure 10. Alloy comparison for 1st Failure in drop tests.

Table 5 Alloy ranking for Mean Failure in drop tests

	9307	1005	1255	6337	3005	6535	4005
Ranking 1X245C + 6Mo/22C	7	5	4	6	1	2	2
Ranking 1X245C + 24hr/22C		3	6	5	4	2	1
Ranking 4X245C + 24hr/22C	5	3	4	7	2	6	1
Effect of 22C Aging		+	+	+	+	+	=
Effect of Multiple Reflows		+	+	-	+	-	+

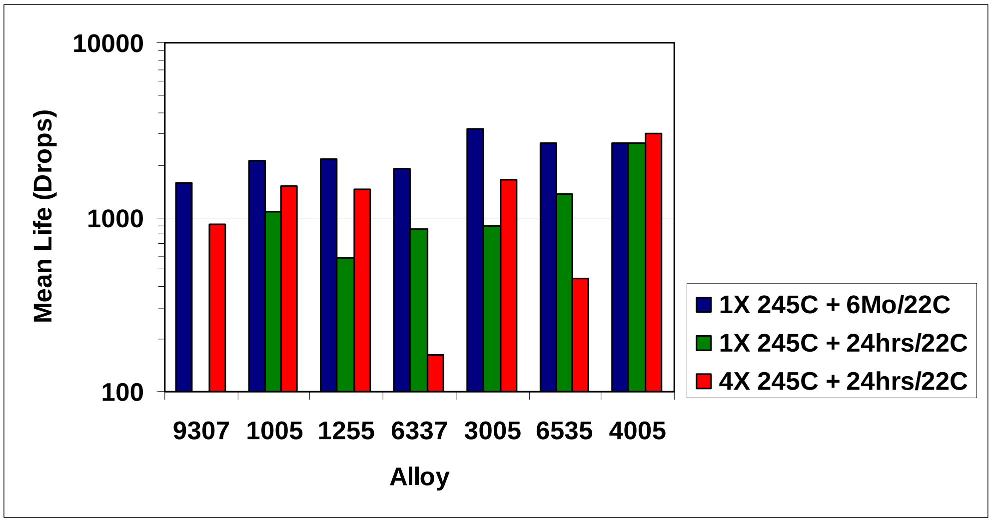


Figure 11. Alloy comparison for Mean Failure in drop tests.

SOLDER JOINT ARRAY TENSILE TEST

Tensile testing of solder joint arrays was performed as described in Refs [2-4]. The samples were formed by soldering a WLCSP to a PCB with solder mask defined pads. The WLCSP sandwiches were glued into fixtures and tested at strain rates between 0.0095/sec and 81/sec at 22C. The strain rate is defined as the crosshead rate divided by joint height. The fraction of joints with a brittle interface failure mode was recorded for each test. The ductile-to-brittle transition strain rate (DTBTSR) was defined at the point where 50% of the joints had a brittle failure mode.

The solder joint array tensile test results for 1 pass reflow + 24hrs / 22C aging are shown in Figure 12. DTBTSR ranged from 2.9/sec to greater than 81/sec. SAC105 and Sn3.5Ag had the best performance.

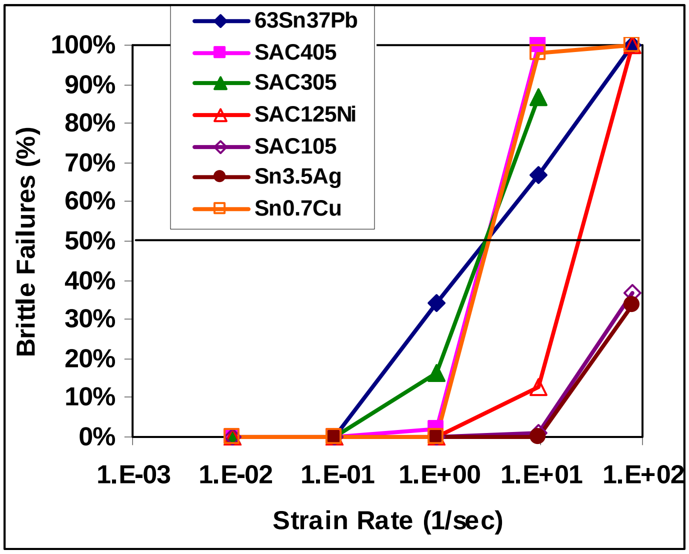


Figure 12. Tensile test results for 1 pass reflow + 24hrs / 22C aging.

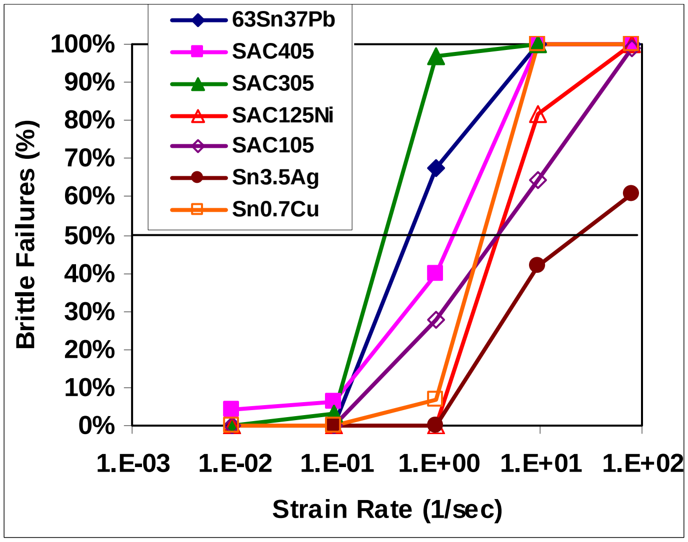


Figure 13. Tensile test results for 4 pass reflow + 24hrs / 22C aging.

Tensile test results for 4 pass reflow + 24hrs / 22C aging are shown in Figure 13. DTBTSR ranges from 0.3/sec to 24/sec. Sn3.5Ag had the best performance.

Tensile test results for 1 pass reflow + 6 Mo / 22C aging are shown in Figure 14. DTBTSR ranges from 3.1/sec to greater than 81/sec. 63Sn37Pb had the best performance.

A summary of DTBTSR for all tests is shown in Figure 15. It is seen that 6 Mo / 22C aging improves performance significantly for 63Sn37Pb and Sn0.7Cu. Four pass reflow had negative impact on performance for all alloys.

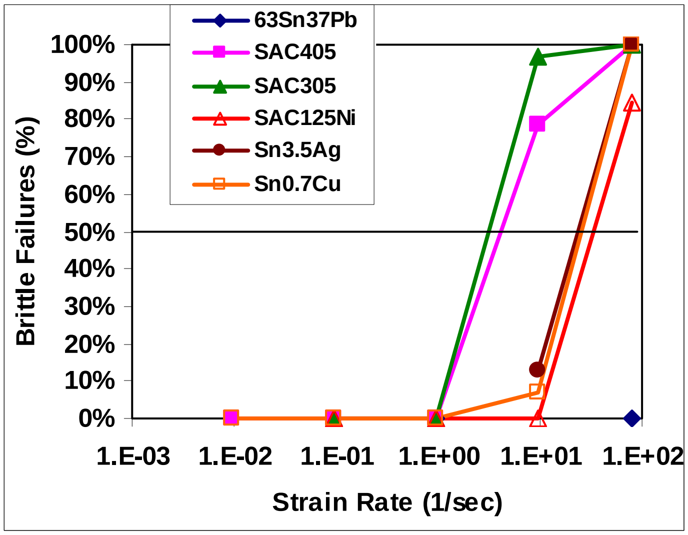


Figure 14. Tensile test results for 1 pass reflow + 6 months / 22C aging.

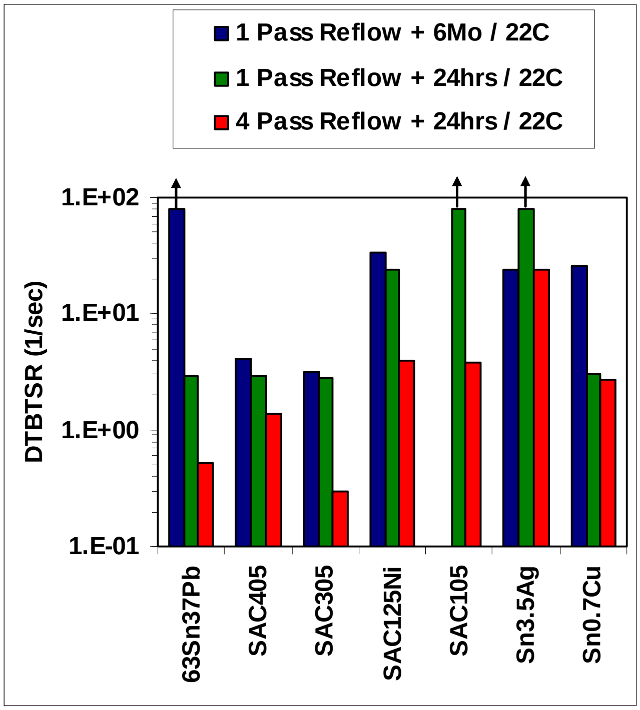


Figure 15. Alloy comparison for ductile-to-brittle transition strain rate (DTBTSR).

CYCLIC BEND TEST

Four point bend testing was conducted per JESD22B113 with the exception that the test board was 4 layer construction (instead of 1-4-1). The support span was 110mm and the load span was 75mm. The load anvil deflection was either 3mm or 4mm. The cyclic frequency was 1Hz. Daisy chain samples were continuously monitored. The 3mm deflection tests were monitored with an event detector set to trigger at 1000 Ohms. The 4mm deflection tests were monitored with a data logger, and a 1ohm increase failure criteria was used. A test board with 9 WLCSPs mounted on it is shown in Figure 16.

Bend test results for samples with 1 pass reflow + 10 mo / 22C aging with 3mm bend deflection are shown in Figure 17. First failures ranged from 2200 cycles to 5200 cycles. Typical failures occurred through the bulk solder on the component side of the solder joints.

Bend test results for samples with 1 pass reflow + 24hrs / 125C aging with 4mm bend deflection are shown in Figure 18. First failures range from 500 to 2500 cycles. Typical failures occurred through the bulk solder on the component side of the solder joints.

The alloy ranking and comparison with respect to first failure is shown in Table 6 and Figure 19. 63Sn37Pb and SAC405 had the best performance. SAC305, Sn3.5Ag, and Sn0.7Cu had the worst performance. The alloy ranking and comparison with respect to mean failure is shown in Table 7 and Figure 20. 63Sn37Pb and SAC405 alloys had the best performance. SAC305, Sn3.5Ag, and SAC125Ni had the worst performance. Tests with 3mm load anvil deflection had 2x to 3x longer life than those with 4mm deflection.

The effect of post reflow aging was evaluated for only the SAC125Ni alloy (code = 1255) and a 3mm deflection condition. The samples with 24hrs / 125C aging had 20% longer life than those with 10 mo / 22C aging.

THERMAL CYCLE TEST

Lead free alloys were tested under four thermal cycle conditions, as shown in Figure 21. A populated thermal test board is shown in Figure 22. Daisy chain samples were continuously monitored, and the event detector was set to trigger at 500 Ohms.

The results for -55C<=>125C, 2cph test condition are shown in Figure 23. First failure ranged from 131 cycles to 304 cycles. Mean life ranged from 170 cycles to 408 cycles. Sn0.7Cu had the best performance and Sn3.5Ag had the worst performance.

The results for 0C<=>100C, 2cph test condition are shown in Figure 24. First failure ranged from 295 cycles to 841 cycles. Mean life ranged from 686 cycles to 1316 cycles. SAC405 had the best performance and Sn3.5Ag and 63Sn37Pb had the worst performance.

The results for 35C<=>110C, 1cph test condition are shown in Figure 25. First failure ranged from 437 cycles to 2403 cycles. Mean life ranged from 1200 cycles to 3500 cycles. 63Sn37Pb had the best performance and Sn3.5Ag had the worst performance.

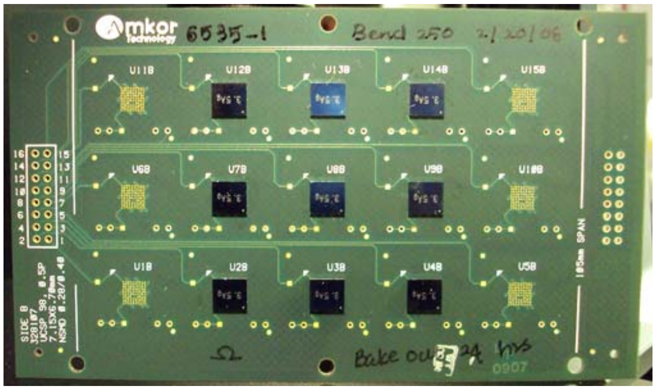


Figure 16. Bend test board with assembled units

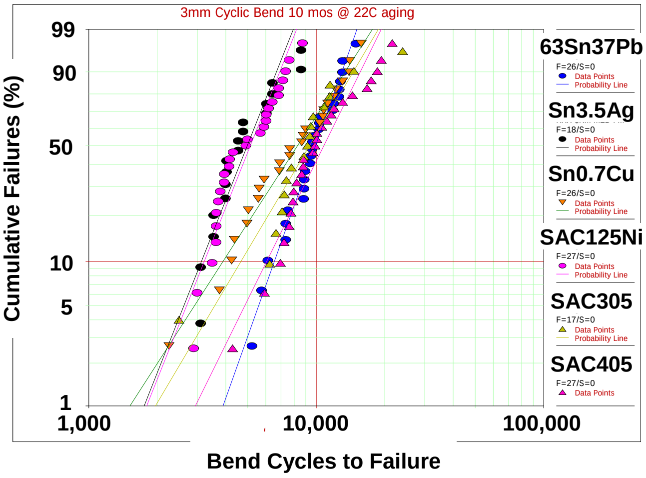


Figure 17. Bend test results for 3mm bend deflection with 1 pass reflow + 10 months / 22C aging.

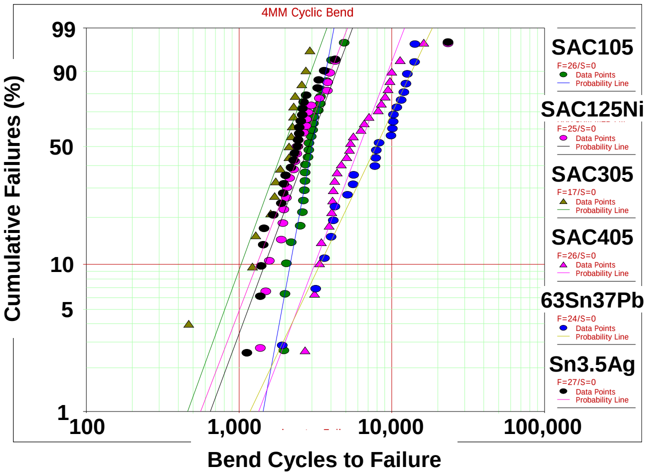


Figure 18. Bend test results for 4mm bend deflection with 1 pass reflow + 24hrs / 125C aging.

Table 6
Alloy ranking for 1st Failure in bend tests

	9307	1005	1255	6337	3005	6535	4005
Ranking 10Mo/22C – 3mm	6		3	1	5	4	2
Ranking 24hr/125C – 4mm		2	4	3	5	6	1

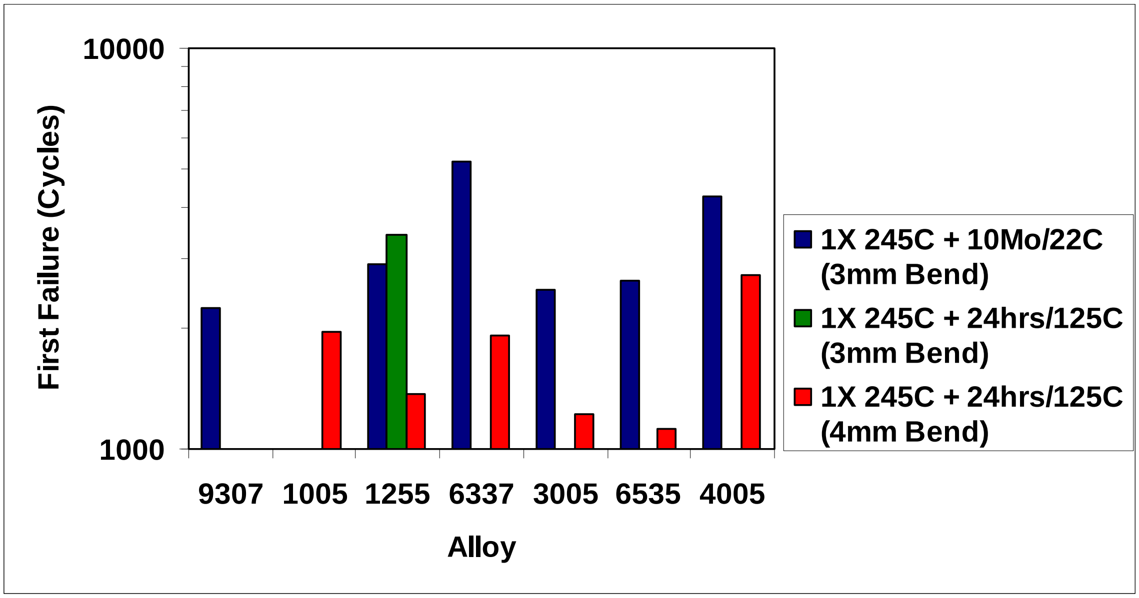


Figure 19. Alloy comparison for 1st Failure in bend tests.

Table 7
Alloy ranking for Mean Failure in bend tests

	9307	1005	1255	6337	3005	6535	4005
Ranking 10Mo/22C – 3mm	4		5	2	3	6	1
Ranking 24hr/125C – 4mm		3	5	1	6	4	2

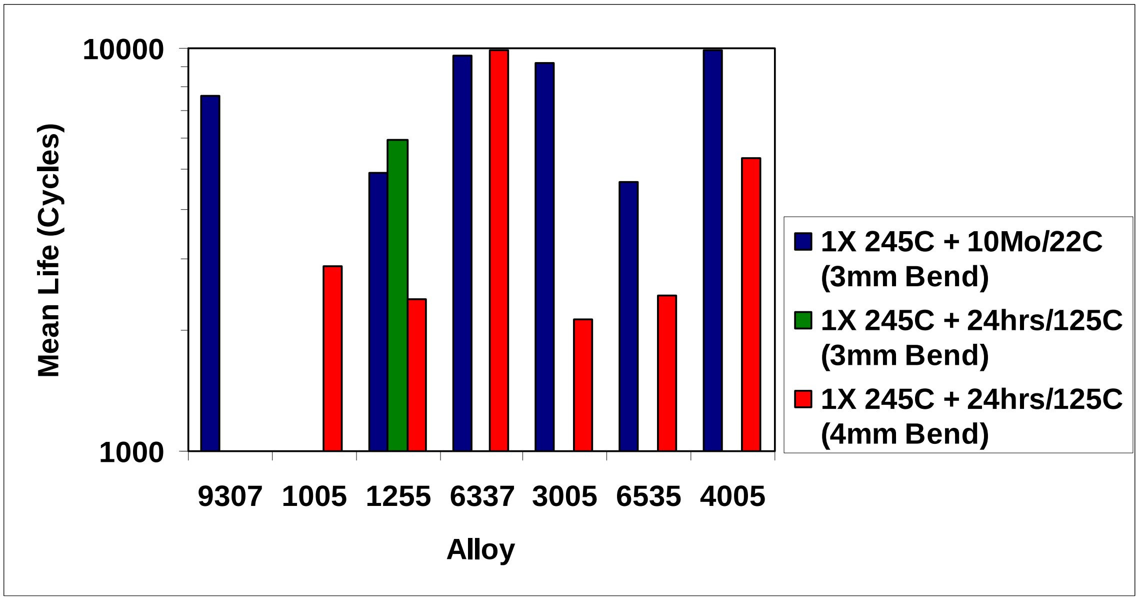


Figure 20. Alloy comparison for Mean Failure in bend tests.

The results for 35C<=>85C, 1cph test condition are shown in Figure 26. First failure ranged from 1801 cycles to 6302 cycles. Mean life ranged from 6500 cycles to 9800 cycles. Sn0.7Cu and SAC405 had the best performance and Sn3.5Ag had the worst performance.

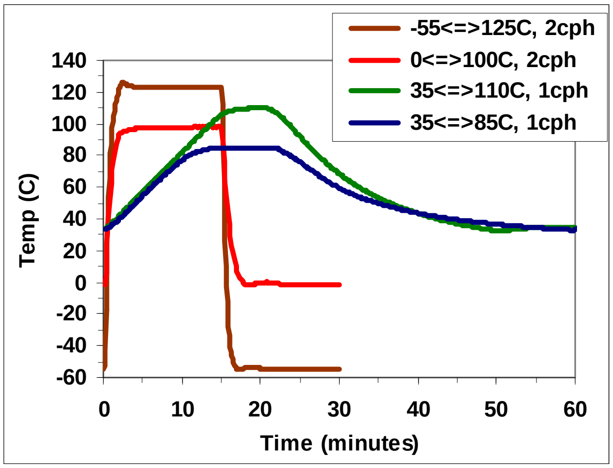


Figure 21. Thermal cycle conditions.

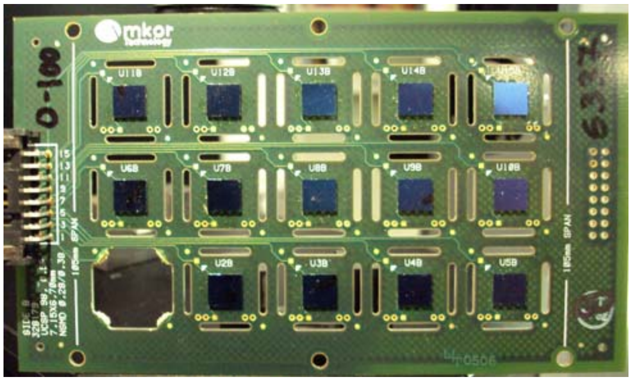


Figure 22. Thermal cycle test board with units.

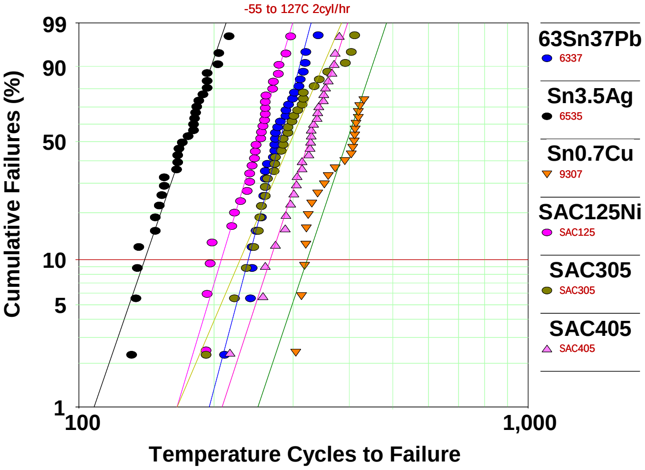


Figure 23. Results for -55C<=>125C, 2cph test condition.

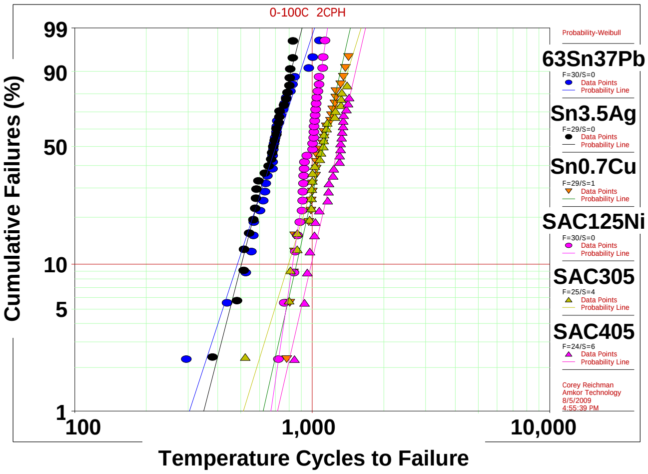


Figure 24. Results for 0C<=>100C, 2cph test condition.

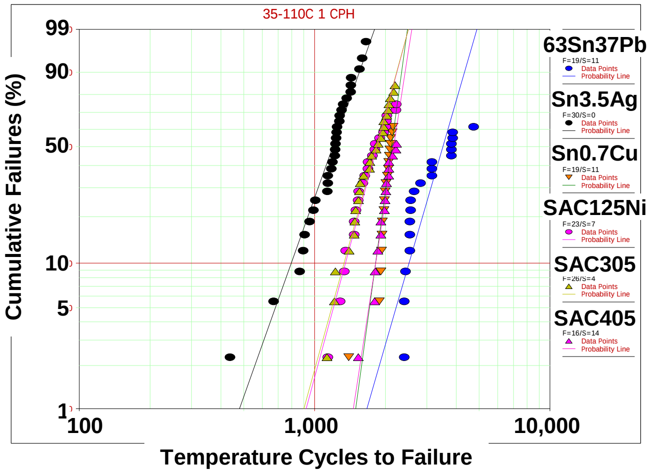


Figure 25. Results for 35C<=>110C, 1cph test condition.

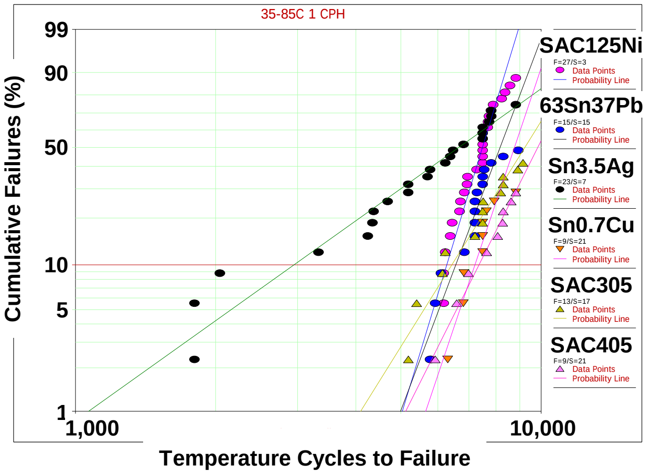


Figure 26. Results for 35C<=>85C, 1cph test condition.

Table 8
Alloy ranking for 1st Failure in thermal cycle tests

	9307	1005	1255	6337	3005	6535	4005
Ranking -55C⇔125C, 2cph	1		4	3	4	6	2
Ranking 0C⇔100C, 2cph	2		3	6	4	5	1
Ranking 35C⇔110C, 1cph	3		4	1	5	6	2
Ranking 35C⇔85C, 1cph	1		3	4	5	6	2

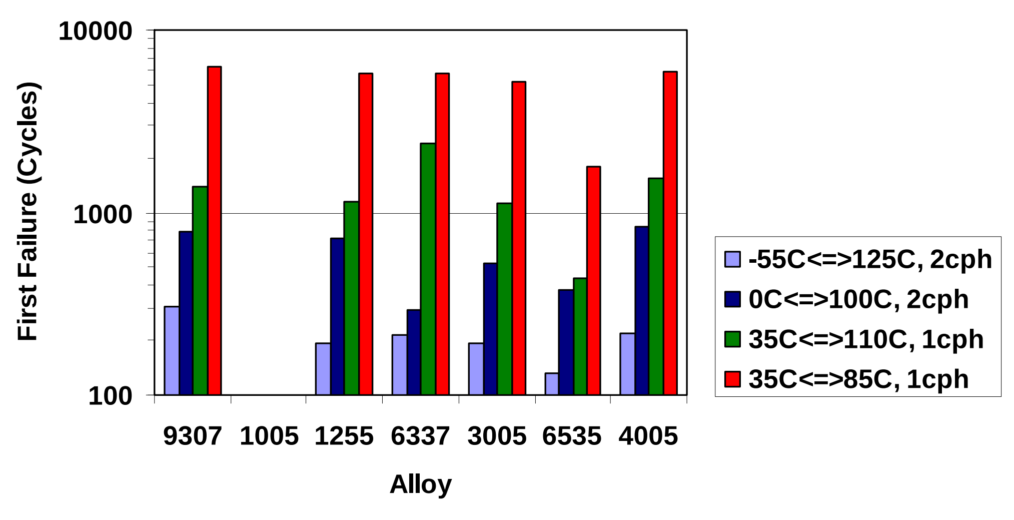


Figure 27. Alloy comparison for 1st Failure in thermal cycle tests.

Table 9
Alloy ranking for Mean Failure in thermal cycle tests

	9307	1005	1255	6337	3005	6535	4005
Ranking -55C⇔125C, 2cph	1		5	4	3	6	2
Ranking 0C⇔100C, 2cph	3		4	5	2	6	1
Ranking 35C⇔110C, 1cph	3		5	1	4	6	2
Ranking 35C⇔85C, 1cph	1		5	4	3	6	2

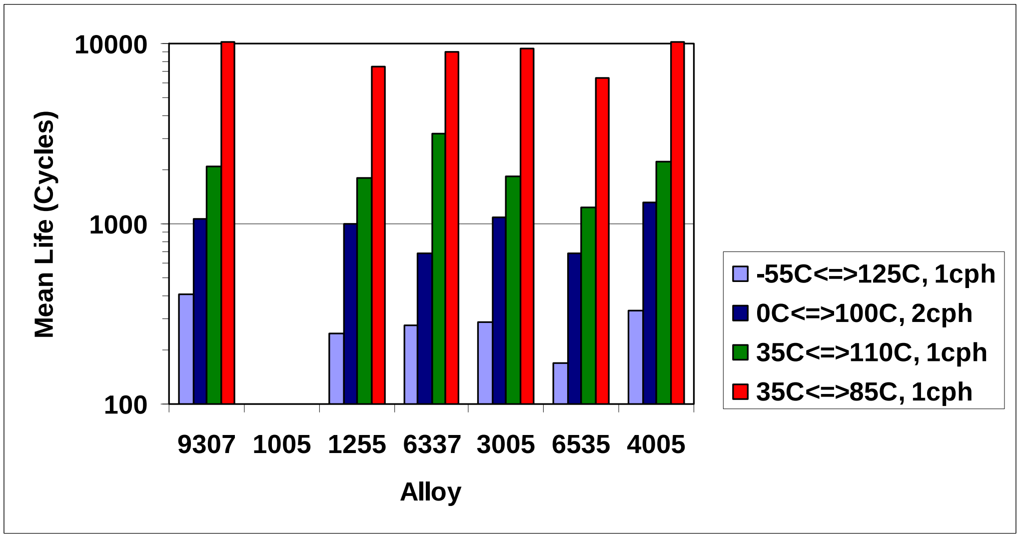


Figure 28. Alloy comparison for Mean Failure in thermal cycle tests.

A comparison of thermal cycle results and alloy ranking with respect to first failure is given in Table 8 and Figure 27. A comparison with respect to mean failure is given in Table 9 and Figure 28. Overall, SAC405 and Sn0.7Cu had the best performance, and Sn3.5Ag had the worst performance. In nearly all cases, the failures occurred through the bulk solder, near the component side of the joint.

The poor performance of Sn3.5Ag was somewhat surprising. There were a few interface failures, but mostly the failures occurred through the bulk solder. One factor might have been the degree of voiding near the component pad metallization. The Sn3.5Ag samples had the most voiding compared to other alloys. It is possible that there was a process related issue during ball attach of the WLCSP. To confirm this possibility, a new lot of samples was put on test.

63Sn37Pb performance was strongly dependent on the temperature cycle conditions. It was the best performer under 35C<=>110C, 1cph, but the worst performer under 0C<=>100C, 2cph.

DISCUSSION

The board level reliability performance of several lead free alloys has been compared under a wide range of test conditions. Cycles to first failure spanned three orders of magnitude. Hence, the test conditions ranged from being quite harsh to being relatively mild.

Although there was no single alloy that performed the best under all tests, SAC405 was the most consistently high ranking performer.

There have been several previous evaluations comparing some of the lead free alloys studied here. Syed [5] evaluated 12mm-144 fleXBGA packages with 0.8mm pitch and electroplated NiAu pad finish using -40C<=>125C, 1cph temperature cycling. The fatigue life ranking in Phase 1 evaluations was SAC405 > 63Sn37Pb > Sn3.5Ag. Under 0C<=>100C, 2cph conditions, the fatigue life ranking was Sn3.5Ag > SAC405 > 63Sn37Pb. In a Phase 2 evaluation under -40C<=>125C, 1cph conditions, the fatigue life ranking was Sn3.5Ag > SAC405 = Sn0.7Cu = 63Sn37Pb. Under -55C<=>125C, 2cph conditions, the fatigue life ranking was SAC405 > Sn0.7Cu > 63Sn37Pb. Finally, under 0C<=>100C, 2cph conditions, the fatigue life ranking was SAC405 > Sn0.7Cu > 63Sn37Pb.

Lin et.al [6] tested non-underfilled flip chip assemblies under 0C<=>100C conditions. The fatigue life ranking was Sn0.7Cu > SAC405 = 63Sn37Pb > Sn3.5Ag.

Clech [7] compiled thermal cycle fatigue data from a wide range of components and test conditions and showed that SAC alloy out performs SnPb at “lower” stress conditions, but SnPb was the best performer at “higher” stress conditions.

Syed et.al., [8] compared alloy performance under drop, bend, and temperature cycling conditions for Ni/Au and Cu/OSP pad finishes. They found that higher Ag content alloys were more favorable under temperature cycling conditions, but lower Ag content was more favorable under drop conditions. The change in drop performance was also accompanied by a change in failure mode; i.e., SAC305 (with lower performance) showed interface failures, while SAC105 and SAC125Ni (with higher performance) failed in the bulk solder.

Considering the results of the present study along with the work cited above, it is clear that comparing the temperature cycling performance of solder joint alloys is not a simple task. There is a complex interaction between the assembly stiffness, expansion mismatch, solder creep behavior, and temperature cycle conditions that determines the amount of damage per cycle [9]. Hence, the relative alloy ranking for one component might not be the same as for another component. Also, the temperature dependence of the creep behavior varies by alloy type [10]. Hence, one alloy might be subjected to the least damage under one temperature cycling condition, but another alloy might be more favorable under different temperature cycling condition. A high thermal cycle ramp rate will likely have a larger impact on alloys with greater strain rate sensitivity (like 63Sn37Pb).

With respect to drop test performance, a key factor is the failure mode. If brittle interface failures are observed, then drop performance is always degraded significantly. The propensity for interface failure depends on two primary factors: 1) the characteristic ductile-to-brittle transition strain rate (DTBTSR) of the solder joints, and 2) the applied strain rate imposed on the joints by the test. If the applied strain rate is greater than the DTBTSR, then interface failures occur readily. The applied strain rate is a function of several factors such as component design and material set, motherboard design and material set, boundary conditions due to restraints on the motherboard, and the level of shock impact loading.

In the present study, there was not a perfect correlation between factors that affected DTBTSR and those that affected drop performance. For example, 6 months / 22C aging improved drop test performance for nearly all alloys, but it only had a significant improvement on DTBTSR for 63Sn37Pb and Sn0.7Cu. Four pass reflow degraded DTBTSR for all alloys, but it only degraded drop test performance for 63Sn37Pb and Sn3.5Ag. Perhaps one reason there was imperfect correlation between DTBTSR and drop test performance was that nearly all of the drop tests had a mixed failure mode or bulk solder failure mode. There was only clean interface failure on 63Sn37Pb with four pass reflow. It is likely that if a larger component had been used in the evaluation (which results in a higher applied strain rate to the solder joints) there would have been better correlation between DTBTSR and drop test performance. Simulations are currently being conducted to estimate the strain rates during the drop test and see how these compare to the measured DTBTSR values for each alloy.

Another reason there could be discrepancy between drop testing and solder joint array tensile testing is simply due to the test method differences. The tensile test is monotonic loading event. Conversely, a drop test is cyclic loading, with multiple bend cycles per drop, and multiple drops per test. The joints do not fail in a single stroke. Also, it is possible that the solder work hardens during drop testing due to repeated loading cycles with very little dwell time in between. For example, it was shown that indium solder joints had a yield stress that varied depending on the previous loading cycle and the amount time for stress relaxation between loading cycles [11].

In the study by Syed et.al, [8], lower Ag content SAC alloys had better drop performance because the failure mode changed from bulk solder failure to interface failure as Ag content was increased. The testing was conducted on a 10x10mm - 360 ball CSP. In the present study, higher Ag content SAC alloys had better drop performance because in all cases the failure mode was either bulk solder, or mixed. The current test vehicle was a 6.8x7.2mm – 98 ball WLCSP.

CONCLUSIONS

1) Board level reliability testing was used to compare six lead free alloys to tin-lead eutectic using a 98 ball Wafer Level Chip Scale Package (WLCSP). The effects of reflow conditions and aging conditions were quantified.

2) In drop testing, first failures were in the range of 4 to 1000 drops. Most samples failed by a mixture of bulk solder and interface failure. Drop test life improved with increased Ag content. The effect of mild aging after surface mount was positive for most alloys. The effect of multiple reflows was mixed.

3) In solder joint array tensile testing, the ductile-to-brittle transition strain rate (DTBTSR) was in the range of 0.3/sec to 80/sec. DTBTSR improved with decreasing Ag content and with room temperature aging, but it degraded with multiple reflows.

4) In cyclic bend testing, first failures were in the range of 1000 to 5000 cycles. SAC405 and 63Sn37Pb had the best performance. A 3mm bend deflection had 2x to 3x longer life compared to a 4mm bend deflection.

5) In temperature cycling, first failures were in the range of 100 to 6000 cycles. Fatigue life increased with Ag content for the SAC alloys. Sn0.7Cu showed good performance under all conditions. 63Sn37Pb showed good performance under 35C<=>110C condition. Sn3.5Ag had poor performance under all conditions due to voiding and some interface failures.

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